AD-A174 425 A PERFORMANCE UPDATE OF THE INTEROCEAN S4 ELECTROMAGNETIC CURRENT METER(U) WOODS HOLE OCEANOGRAPHIC INSTITUTION MA P R CLAY ET AL. OCT 86 1/1

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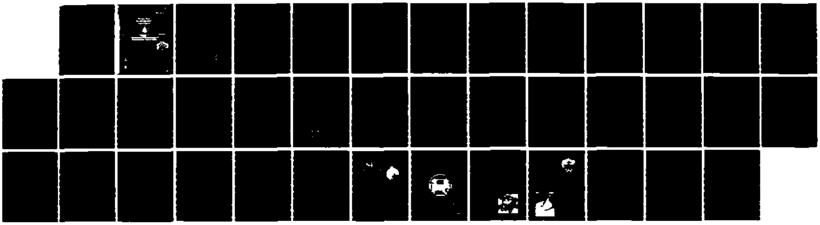

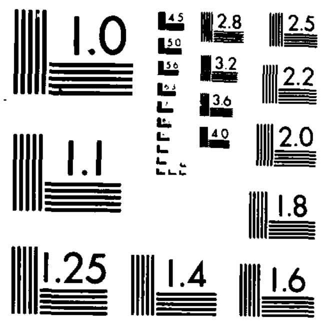

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WHOI-86-42

Woods Hole Oceanographic Institution

by

P.R. Clay and S.P. Longworth

October 1986

Technical Report

Funding was provided by the Office of Naval Research under contract No. N00014-82-C-0019.

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Robert C. Spindel, Chairman
Department of Ocean Engineering

ABSTRACT

This report reviews the working principles of the InterOcean S4 electromagnetic current meter and outlines the practical difficulties and engineering solutions to convert these basic principles into a working instrument.

Presented are the test procedures and results performed on three production units placing emphasis on the oceanographic users point of view. These tests, performed by the Ocean Structures and Moorings Laboratory, Ocean Engineering Department, Woods Hole Oceanographic Institution (WHOI), include laboratory, dockside, and both surface and subsurface mooring tests. S4s are compared to each other and to other types of current meters in various intercomparison tests.

Results of this evaluation program are next summarized. Also, suggestions for areas of improvement and further developments are made. Finally, recommendations for the acceptance, calibration, and burning in of new instruments conclude the report.

The title on the title page is correct for this report.
Per Mrs. Brenda Batch, ONR/Code 112AO

ACKNOWLEDGMENTS

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Our appreciation also goes to Susan Tarbell, Laurel Moore and Betsey Hirschel for their assistance in preparing the text and figures.

This work was supported under ONR contract N00014-82-C-0019.

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1. Introduction

The deployment of instrumentation on moorings in areas of deep abyssal plains has become standard practice at the Woods Hole Oceanographic Institution. Interest in recent years has also turned to surface and high current, near surface moorings. Mooring performance, longevity and data acquisition on these newer, more vulnerable types of moorings has not yet been fully tested nor developed to an operational status. Wave dynamics and strumming due to high currents impose loads causing fatigue, wear and accelerated corrosion. High drag on mooring components causes high tension in surface moorings and results in large dips of subsurface moorings. Through the use of small, low drag, light weight instrumentation these moorings could be deployed for extended periods of time with less deterioration and improved performance.

The InterOcean S4 current meter is one such type of "mooring friendly" instrumentation. It is both light weight and small with a favorable shape, therefore providing very little additional mooring line forces.

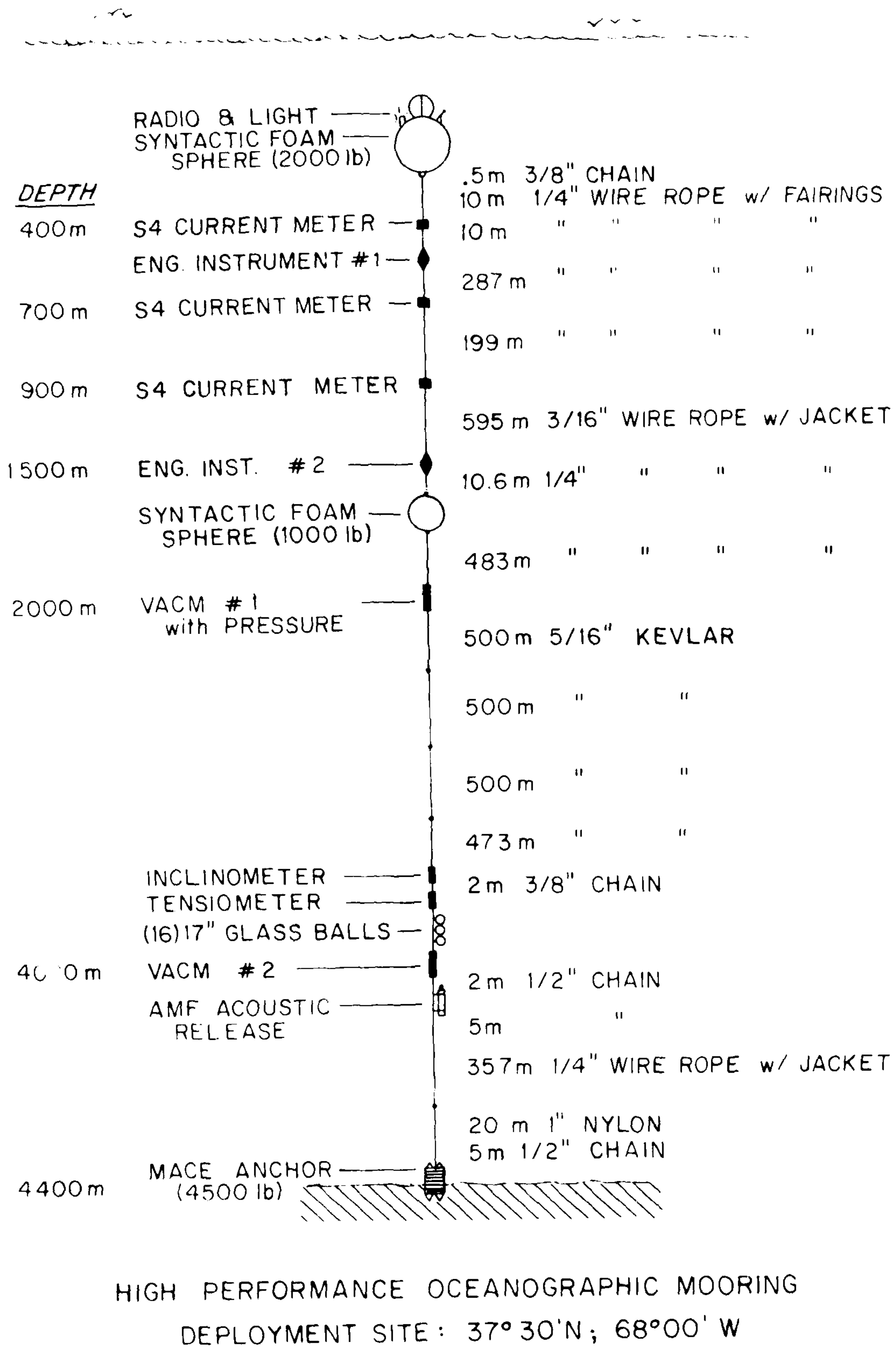
This paper evaluates the performance of three standard units all ordered with the temperature and depth option. Our primary goal is to document the procedures used to help insure S4 reliability and accurate data return. This was accomplished by first learning how to effectively communicate with the instrument. The next step was to obtain a good understanding of the instrument's operational and programming characteristics. Then, lab tests and calibration of the S4's sensors were performed. Comparisons with other instruments of known data return reliability and accuracy were completed prior to a two month deployment in the Gulf Stream at approximately 37°N and 68°W (See Figure 1).

2. Review of S4 Current Meters Working Principles

Many conventional current meters use rotors or propellers to measure flow velocity and vanes to measure flow direction with respect to the instrument casing. A gimballed compass in turn senses the orientation of the casing with respect to the earth's magnetic field. Traditionally these instruments suffer from: bearing friction which limits the threshold of measurable currents; uneven rotor acceleration and deceleration rates; susceptibility to bearing destruction in high current regimes; rectification due to uneven vane response to wave action; and limited compass accuracy.

These limitations have lead to the development of newer types of current meters, free of moving parts, based on either acoustic or electromagnetic measurements. The working principles of the electromagnetic S4 current meter are hereafter briefly reviewed. The manufacturer's data and specification sheet can be found in Appendix A.

Electromagnetic current meters measure the voltage resulting from the motion of the conducting sea water through a magnetic field generated by the instrument itself. This voltage, $\vec{E}$, is the difference between the electromotive potential created in the surrounding volume and the small electrical current resistive losses within this volume.



1. **HIPOM Mooring Schematic**

The familiar expression used to calculate this voltage is:

$$\vec{E} = \iiint (\vec{V} \times \vec{B} - \vec{J}/\sigma)\, dV$$

Where $\vec{V}$ = water velocity

$\vec{B}$ = magnetic field intensity

$\vec{J}$ = electric current

σ = sea water conductivity.

dV = volume element

In practice, the voltage, $\vec{E}$ (typically microvolts), is far too small to measure as a dc potential, the most stable of electrodes commonly exhibiting half-cell potential variations of millivolts. This problem can be solved by modulating the magnetic field, $\vec{B}$, at a frequency high with respect to the electrode potential variations thus permitting synchronous detection of the voltage, $\vec{E}$. To this end a coil is mounted at the instrument equator. A varying current passing through the coil produces a modulated vertical magnetic field uniformly distributed in the horizontal plane. Sea water passing through the field in turn produces a modulated EMF field. Diametrically opposite pairs of electrodes sense the X and Y components of this field. The voltage information is then translated by the onboard computer in the X and Y components, U_x and U_y, of the water velocity.

A low power flux gate compass is used to sense the orientation of the current meter in the earth's magnetic field. If H_x and H_y are the X and Y components of this field, then the North and East components of the water velocity, U_n and U_e, are given by:

$$U_n = (U_x H_x - U_y H_y) / (H_x^2 + H_y^2)^{1/2}$$

$$U_e = (U_x H_y + U_y H_x) / (H_x^2 + H_y^2)^{1/2}$$

A microprocessor performs data preconditioning and controls operating format under user-initialized EPROM instructions. Oceanic currents may be recorded as burst samples or vector averages. Optional parameters such as conductivity, temperature, depth, and tilt may also be selected for recording with the current measurements.

To perform vector averaging, N samples of U_n and U_e are individually accumulated (added up) where N is any number between 2 and 65,535 corresponding to intervals between 1 second and 9 hours. At the end of the averaging interval, the accumulated totals are divided by N, and a single number pair (U_n and U_e) is recorded.

Up to 90,000 vector measurements may be stored in 256K bytes of protected internal solid-state memory. The operating mode may be programmed and data retrieved from the S4 without opening the instrument housing. The batteries which supply the main power to the S4 are housed in a separate compartment from the electronics. These batteries may be changed in the field without exposing the electronics to the environment. The CMOS solid-state memory is backed up by an independent lithium battery with a ten year life. No data is lost from memory during main battery replacement. Up to 2300 hours continuous logging is possible using only six (6) lithium "D" size cells. Therefore, the S4 can be deployed, in principle at least, for in excess of three (3) months in a continuous logging mode or for more than three (3) years in a periodic logging mode between battery changes.

A detailed description of the S4 current meter working principles and performance is presented in the Proceedings of Oceans '83 (Lawson, et al., 1983).

3. WHOI Test and Evaluation Program

3.1. General Acceptance and Initial Performance Testing.

The InterOcean S4 current meters are shipped with the battery packs ordered with the units. Upon receiving each unit it is first interrogated using RS232C protocol through an interface box which allows communication with a terminal. S4 application software for use with the HP85, HP9826, or IBM PC compatible computers is available from InterOcean Systems. We obtained an early version of the HP85 software for communications and data processing. This program would often quit running when an improper key was pressed, making the program difficult to use. Most of our testing and programming of the S4s was therefore done with an HP85 computer using a program developed at WHOI.

Gaining experience in programming and offloading data from the S4 is best done while bench testing. Static bench testing is performed by simply placing the S4 in the logging mode. After logging is completed the offload software is tested. With the formulas supplied in the S4's Owners Manual (InterOcean, 1985), data retrieval and conversion to engineering units with other computers is fairly straight forward. We have written programs to offload the S4's data directly into our VAX system, allowing data processing and subsequent comparison of the S4's data with other instruments also offloaded to the VAX. All of our comparisons were done using time series plots with comparable sampling intervals.

One of the most important and relatively simple measurements which can be made on the bench is the instrument's current drain while in the record mode. Specific battery drain tests were initially performed because of frequent premature shutdowns due to excessive current drain of 50 to 70mA. InterOcean repaired the problems, which were primarily caused by faulty or defective electronic components.

Battery current drains can very significantly from instrument to instrument, and therefore should be checked in order to determine battery life expectancy. With an ammeter in series with the S4's main battery pack, our S4s measured: #1 = 26mA, #2 = 28mA, and #3 = 35mA. All subsequent tests and deployments were performed using alkaline "D" cells, except for one deployment with lithium batteries.

We first performed a battery drain test of S4 #1 at room temperature. The S4 was programmed for continuous logging with depth and temperature recorded every 12 hours. Measuring the S4's battery voltage and current drain twice a day we were able to plot a voltage versus time curve. The graph resembles the classic alkaline battery discharge curve.

The total lifetime can be estimated using a simple formula. Alkaline "D" cells have a room temperature rated capacity of 10 Ah, which we derate to 8.0 Ah to account for the low operating temperature.

Defining a duty cycle, D/C, to be the ratio of cycle time to on time, instrument lifetime in hours is:

$$T = (8.0/I)(D/C)$$

where I is the measured current drain. Calculated lifetime was 12.8 days; observed lifetime was 17.7 days to shutdown, which occured at 6.28 volts.

S4 #1 and #2 were then battery drain tested in our environmental chamber at approximately 35^{o}F. The S4s were duty cycled 1 minute on, 1 minute off (or a D/C equal to 2). The results of this test were also very good. S4 #1 shut down at 5.58V after 28.25 days, which is up 10% from the calculated 25.63 days. S4 #2 shut down at 5.74V after 28.04 days, which is up 18% from the calculated 23.8 days.

From the above battery drain tests, we conclude two major points: The S4s do operate in the cold; and the formula used for battery life expectancy is a valid one. These burn in tests give us greater confidence in the ability of the S4s to operate for their designed battery life time.

3.2 Laboratory Testing

Temperature tests. Temperature tests were performed on all three S4s to determine the accuracy of their temperature circuits. Testing was tedious due to the long time constant of the instrument. It takes a minimum of one hour for the instrument to react to an outside temperature change because the sensor is located inside the pressure case.

We chose to test the instruments in a small water bath. The instruments were placed in the bath, and the water temperature was varied in steps from 0° to $20^{\circ}C$. A $0.01^{\circ}C$ readable NBS traceable thermometer was used to monitor bath temperature. The S4s were left in the bath for a full hour at the test temperatures, at the end of which their output and the thermometer readings were noted.

Temperature variations around the instruments and at the walls of the bath introduced inaccuracies in the temperature data recorded by the S4s. Yet the maximum difference between S4s #2 and #3, and the NBS thermometer measurements was found to be $0.2^{\circ}C$ which is within the specified accuracy of the S4.

However, S4 #1, when tested in the same way, showed a constant offset of $+1.2^{\circ}C$. Further testing of the three instruments suspended in series from the WHOI dock showed the S4 #2 and #3 temperature data to be virtually identical, while the S4 #1 temperature data had a constant $+1.4^{\circ}C$ offset. This $+1.4^{\circ}C$ offset will be used to correct the instrument's future temperature data instead of the $+1.2^{\circ}C$ offset because of the small bath temperature uncertainty. To accomplish this correction, 1.4° will be subtracted from every temperature data point during the data offloading of the S4.

Pressure tests. S4s #1 and #2 were pressure tested at the Benthos, Inc. pressure facility in North Falmouth, Massachusetts. The accuracy of the pressure monitoring equipment is +/- 3.5 dBars. The specified accuracy of the S4 is +/- 2.5 dBars with a range of 0 to 1000 dBars.

S4 #1 was pressurized to 1000 dBars for 5 minutes at the beginning of the test to confirm the mechanical integrity of the instrument. At the rated full working depth (1000 M.), no physical problems were encountered. A new cycle was then started with the pressure increasing from 0 to 686 dBars in 137.9 dBar steps (0 to 1000 psi in 200 psi steps). The results of both S4s are plotted in Figure 2.

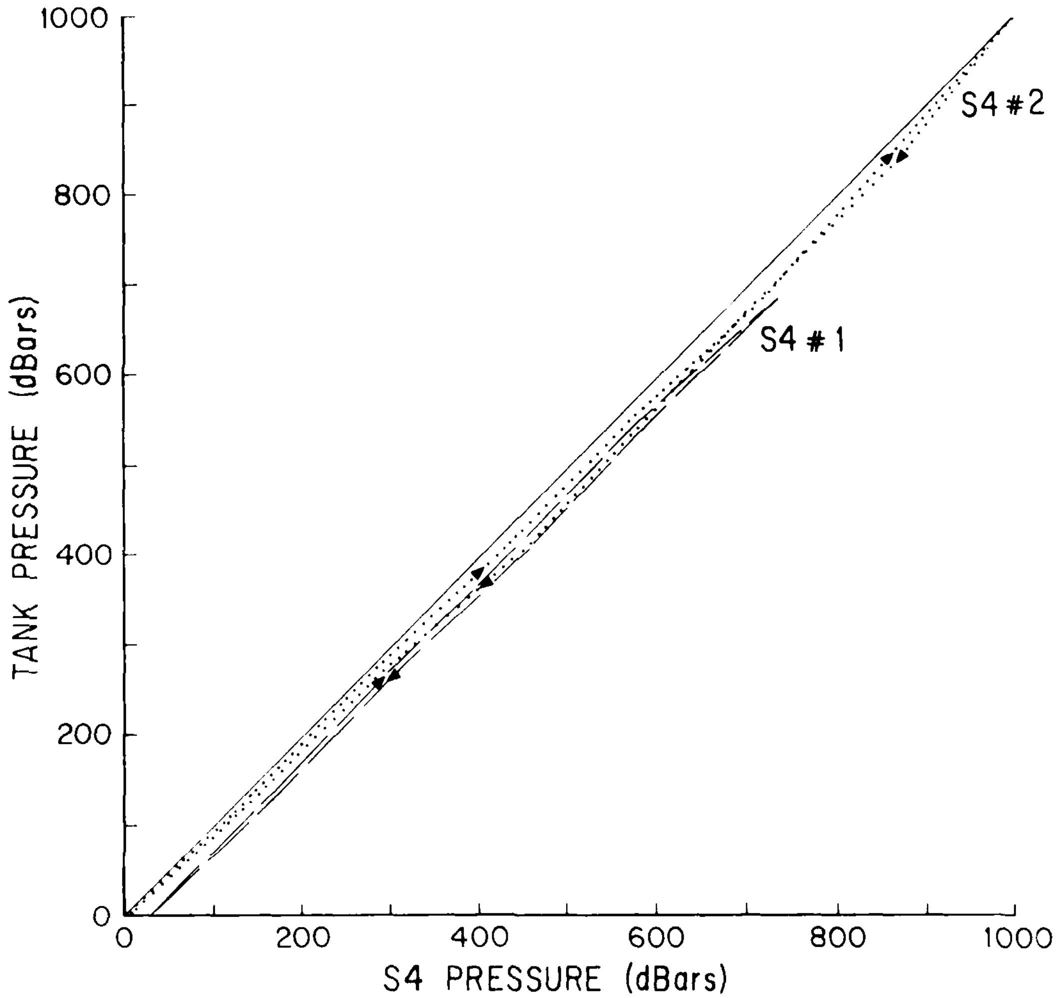


Figure 2. S4 Pressure Tank Test

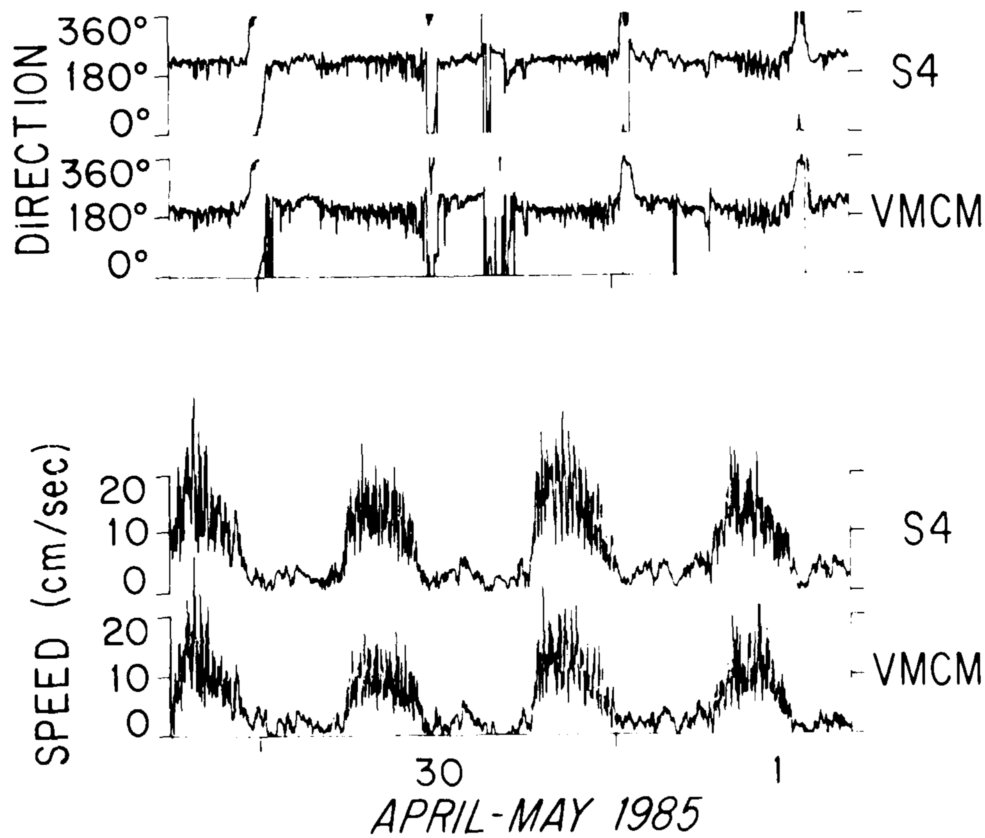
Evident is the 32 dBar offset at 0 pressure and 46 dBar offset at 686 dBar pressure. Some hysteresis is also apparent in the plot.

S4 #2 was next cycled from 0 to 1000 dBars in 137.9 dBar steps. There appeared to be a 7 dBar offset at 0 pressure. At rated full pressure (1000 dBars), the S4 measured precisely 1000 dBars. Some hysteresis and nonlinearity in the mid-range portion of the curve could also be seen.

The results show that the differences in the pressure measuring system of each instrument is significant and that additional data processing has to be applied to the raw data to compensate for the offset and nonlinearity in the instruments. InterOcean has since changed suppliers and now provides a pressure sensor manufactured to significantly improve performance and quality control specifications. Calibration curves are also provided with each S4 delivered with the pressure option.

Tow Tank tests. A series of tow tank tests was performed in the WHOI small tow tank in order to measure the instrument drag and internally record rough speed and direction. The drag, or the net force in the direction of water flow, on the instrument was found to be a function of the instrument angle with the vertical. At 2 knots the drag was 6.3 lbs. when vertical. It decreased to 5.0 lbs. at a 20^{o} inclination at the same speed. Speed and direction measurements were found to be reasonably accurate, with some discrepancies introduced by the tank metallic frame. The fundamental operation of the instrument was thus checked and better tests of current measurements could then be devised and pursued.

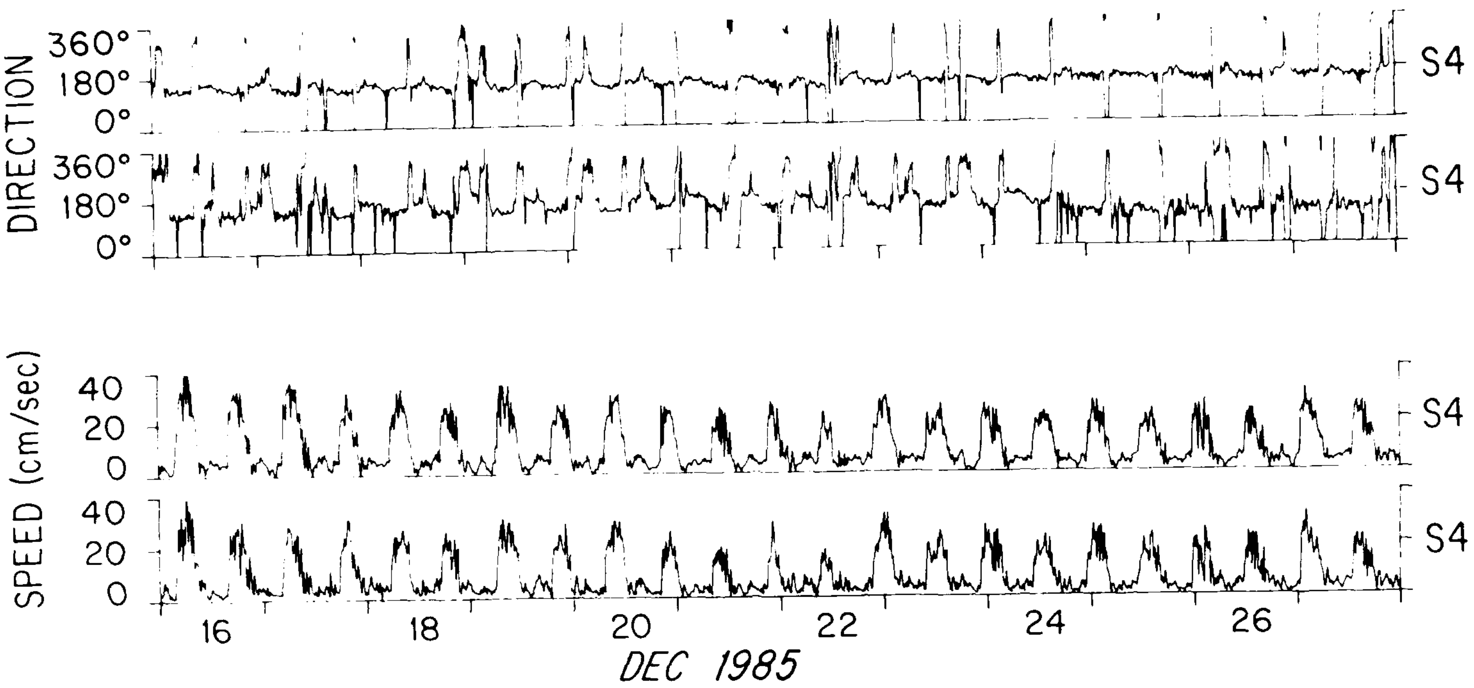
Dock tests. In order to further evaluate the S4 current meter a short 3 day deployment was performed off the WHOI dock. Suspended just below the S4 was a VMCM and a tensioning weight to hold the mooring line vertical. The approximate instrument sensor depths were 2.5m for the S4 and 3.5m for the VMCM. Figure 3 shows the speed and direction time series of the 3 day experiment. It can be noted that the frequency of speed fluctuations and the magnitudes of the current are in agreement during the first day after deployment, but then the speed magnitude differences seem to increase significantly with the VMCM reading about half of the S4 at the end of the record. The speed directions are consistent throughout the record. This VMCM had been extensively used prior to this experiment without refurbishing and was found to have sticky bearings after the test.



3. **VMCM/S4 Dock Test Time Series**

Another dock test of three S4s suspended in series was then conducted for a month. The meters were placed at 2m, 3m, and 4m, respectively below the high water line. Results are shown in the time series of Figure 4. Only two records are shown. The third S4 failed to record any usable data because of a programming error prior to deployment. Excellent correlation of the other two instruments did, however, exist for the duration of the experiment. The twelve hour tidal cycle is evident with strong flow to the East for six hours followed by essentially no flow (less than 5 cm/sec) for the next 6 hours. Monthly moon effects can also be seen in the plot with strong currents around mid month, and again at the end of the month.

Sea towing tests. Following the two relatively low speed dock experiments, a short intercomparison test of an S4 and a VMCM was performed off the stern of the R/V ASTERIAS while towing at various speeds. A 1500 lb. weight was suspended below the S4 and the VMCM (Figure 5). The instruments were then lowered by the ship's winch to depths of about 4m and 2m, respectively, off the stern quarter. Towing speeds while steaming in one direction were changed from 0 to 8 knots in 2 knot increments. After the run to 8 knots, the ship was slowed, the VMCM hauled out of the water, modified and then lowered again. The S4 stayed in the water for the entire test duration. The speed was then again increased in 2 knot increments to 8 knots and the cycle was repeated. This cycle was repeated three times as evidenced in the time series plot of Figure 6.



4. S4 Dock Test Time Series

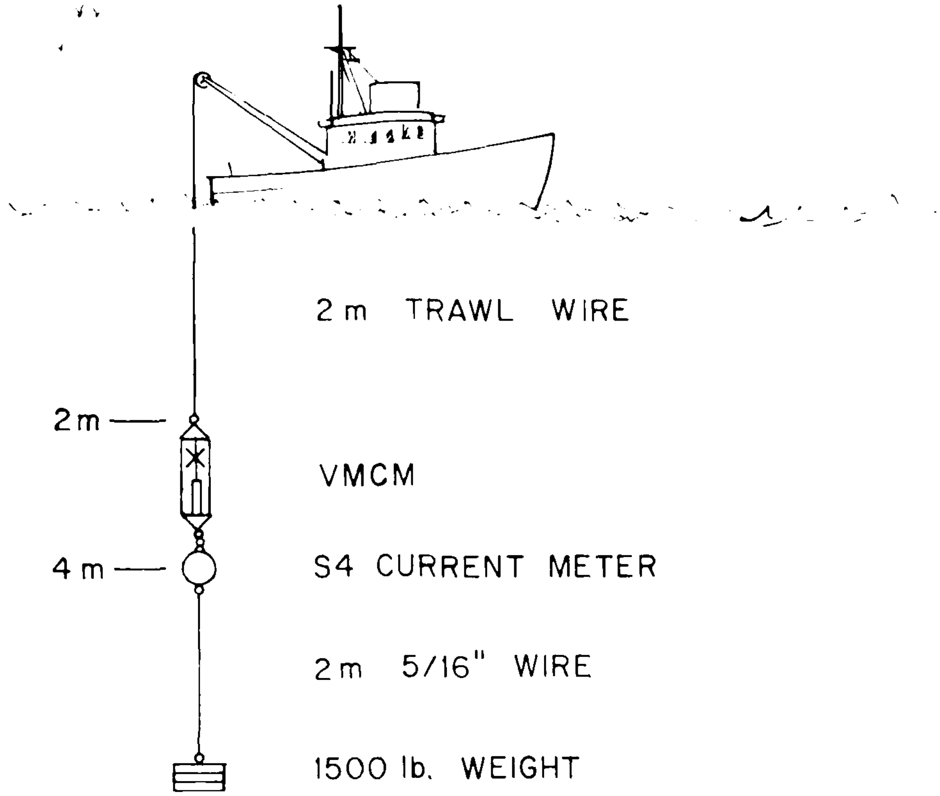


Figure 5. ASTERIAS VMCM/S4 Tow Test

At high speeds the VMCM measurements are found to be less than those of the S4. This may be explained by the cosine response of the VMCM as its inclination increases with speed. At the slower speeds, 2 to 4 knots, there is, however, good agreement between the two records. The high VMCM

spikes after the speed decreases are due to the props spinning in air just prior to blocking the rotors. There is also a high spike following the cage sting modification when the rotors were unblocked and again exposed to the wind. Once back in the water the two instruments then agreed again.

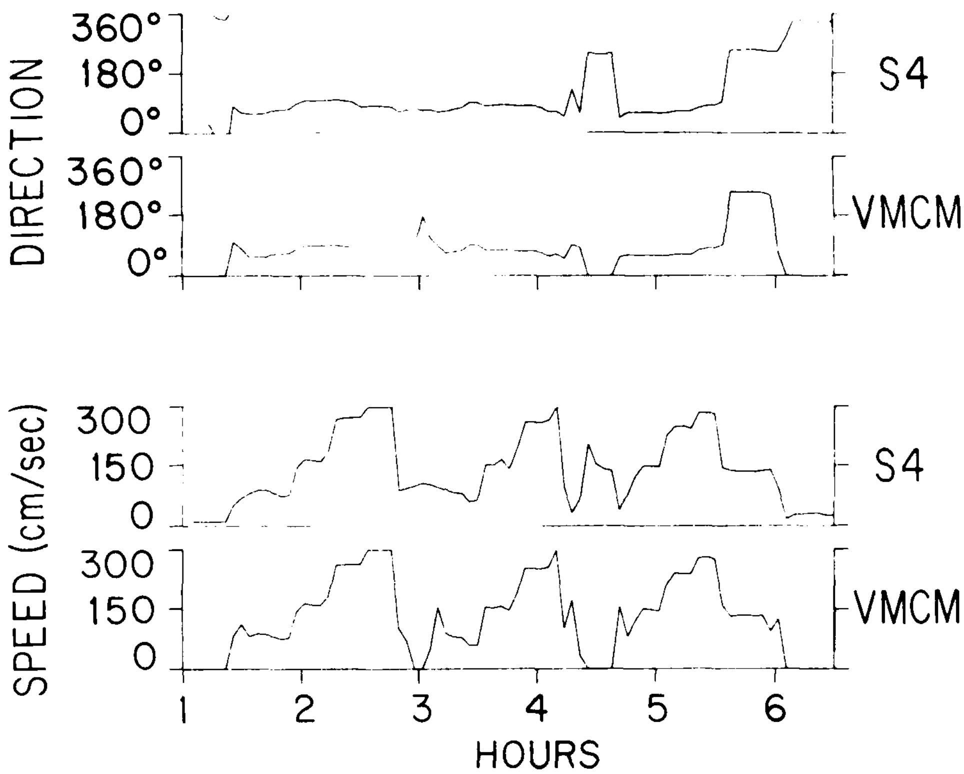


Figure 6. R/V ASTERIAS VMCM/S4 Tow Test Time Series

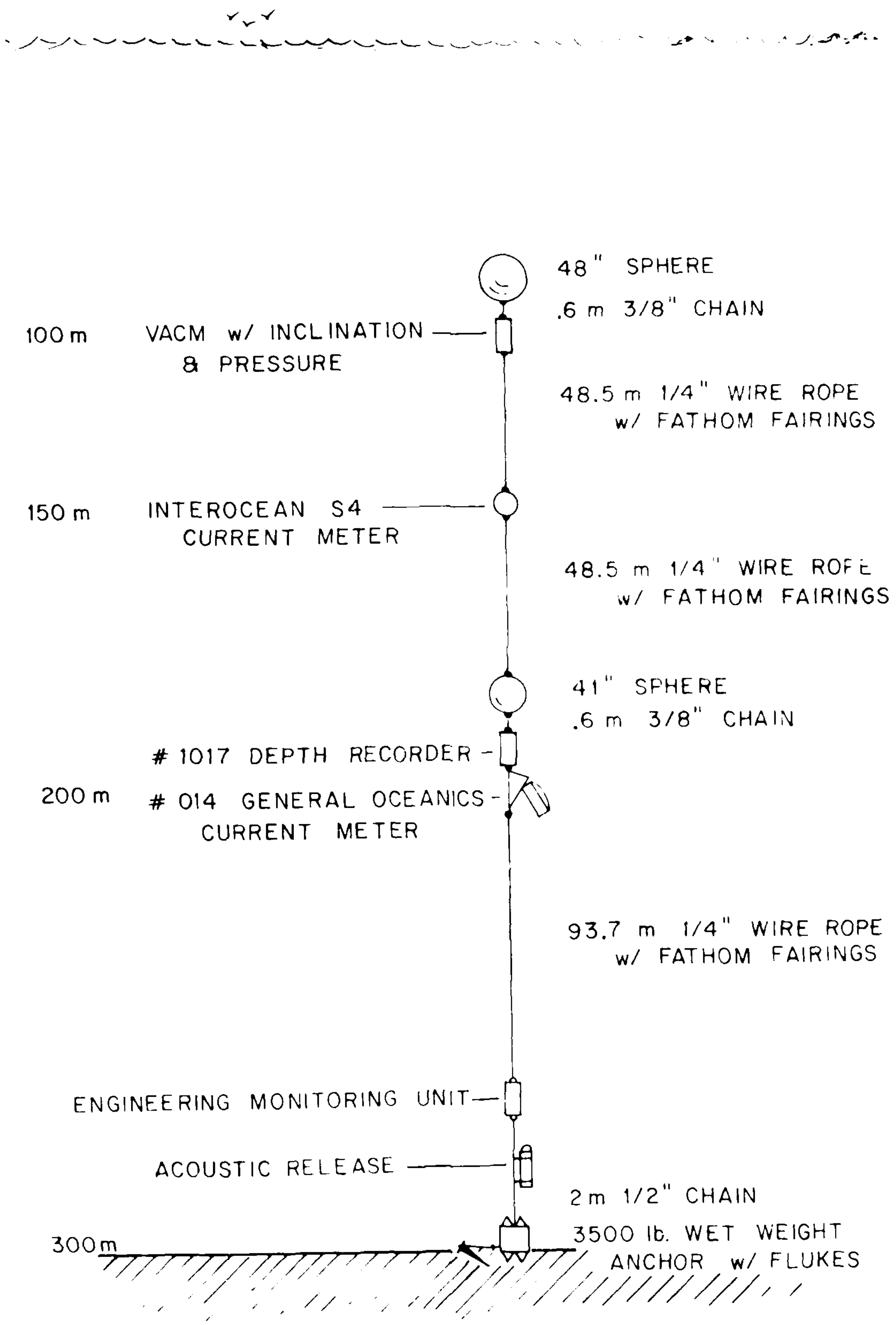
A yoyo-ing experiment for 16 minutes at approximately 3 knots boat speed was conducted by raising and lowering the instruments 3m in a 12 second period. Directions agreed very well as did the recorded speed although the VMCM was about 3 cm/sec lower than the S4 (about 2% low).

3.3 Operational Tests

The first actual at sea use of an S4 current meter by WHOI took place with a factory provided instrument on a subsurface mooring during a pilot experiment in the Straits of Gibraltar in 1984. Mooring placement in the Straits was directly on the sill in a very high current area.

A 200m engineering mooring in 300m water depth was deployed both with and without rigid fairing on the wire rope to determine how beneficial the fairing was to mooring performance. The S4 was deployed both times on this mooring at 150m depth, 50m below an EG&G VACM (Figure 7). The time series plots of the two current meters are shown in Figure 8. These, of course, are not expected to agree because the instruments were not next to each other on the mooring and a strong baroclinic current profile is known to exist there. However, some consistency is evident. Indications to date imply that reasonably good data is recorded by the S4 current meter even in very high current regimes. Speeds of over 4 knots were recorded by both the S4 current meter and the VACM.

Another at sea intercomparison between the VMCM and the InterOcean S4 was conducted on a shallow water surface mooring in Buzzard's Bay, Massachusetts. The water depth was 14.6m and the experiment lasted about 45 days in the late Spring of 1985. Instrument layout was as depicted in Figure 9, with all instruments having the same 4 minute sampling interval. The S4 was deployed using lithium batteries to extend its operating life to 50 days. This is 4.5 times longer than the expected life using alkaline batteries. Unfortunately, the S4 developed



7. Gibraltar Mooring Schematic

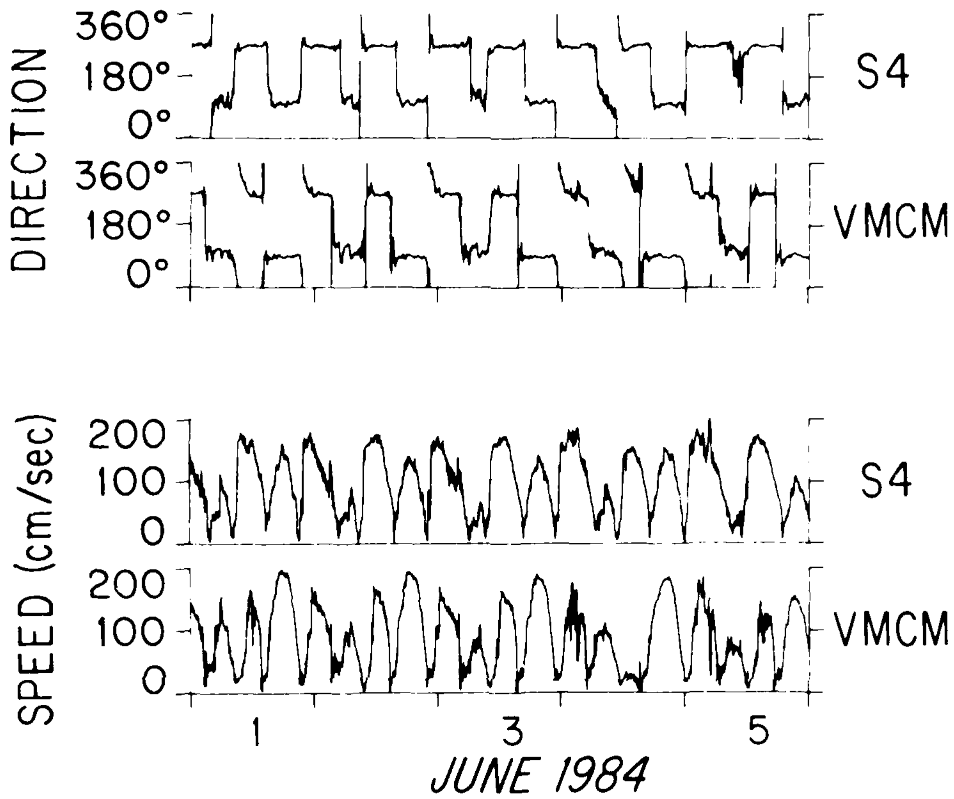


Figure 8. Gibraltar Mooring VACM/S4 Time Series

electrical problems in its depth circuit which increased current drain from 28 to 75 mA. The S4 prematurely shut down 32 days after deployment. Only 20 of these days have reliable data due to the eventual deterioration of the internal reference voltage caused by the depth circuit malfunction.

The S4 was also shown to have a clock problem resulting in a stretched time base. The sampling interval was 4.002 minutes instead of 4.000 minutes, thereby, complicating data comparison between the S4 and VMCMs. InterOcean has since improved the accuracy of the sampling

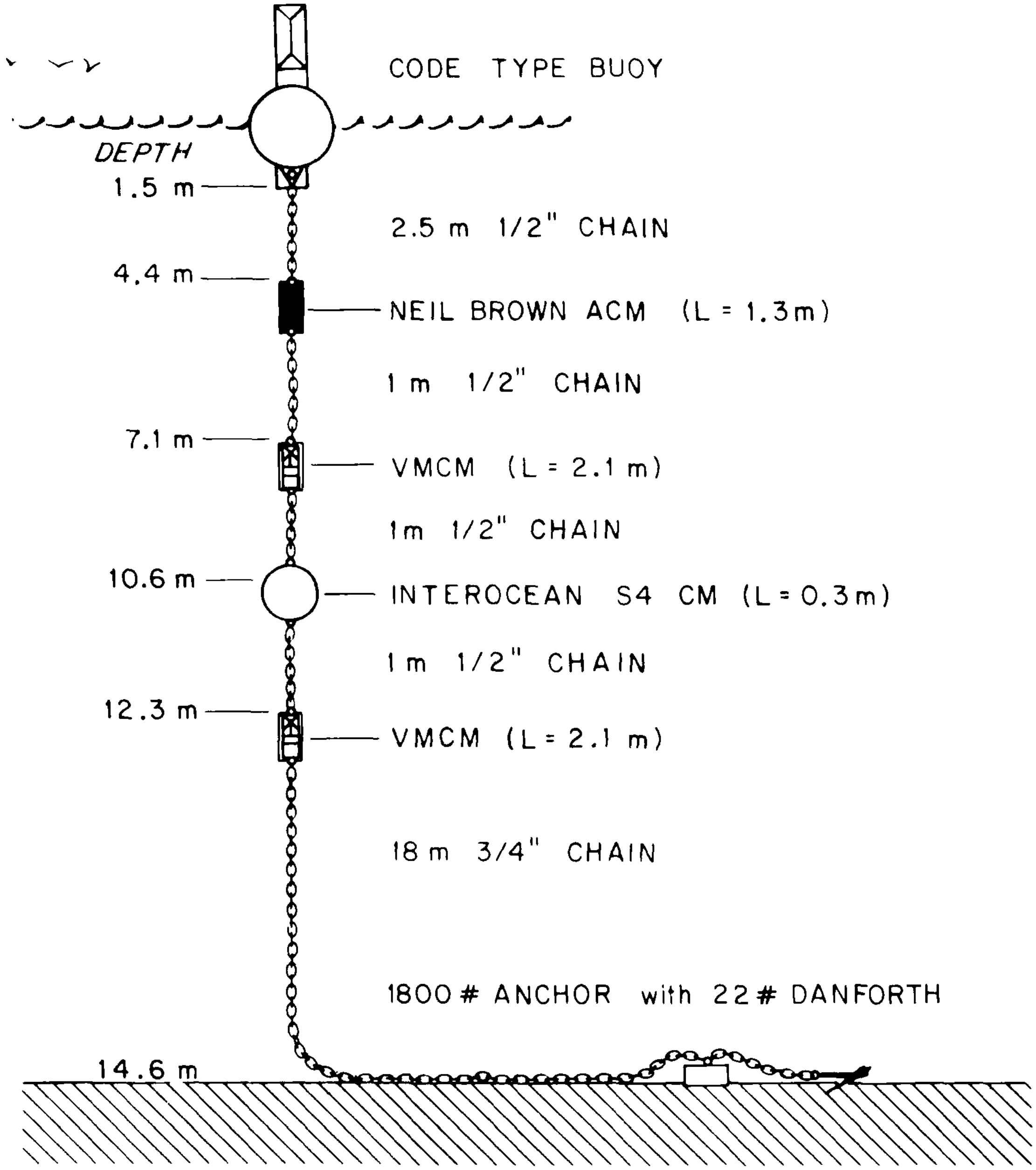
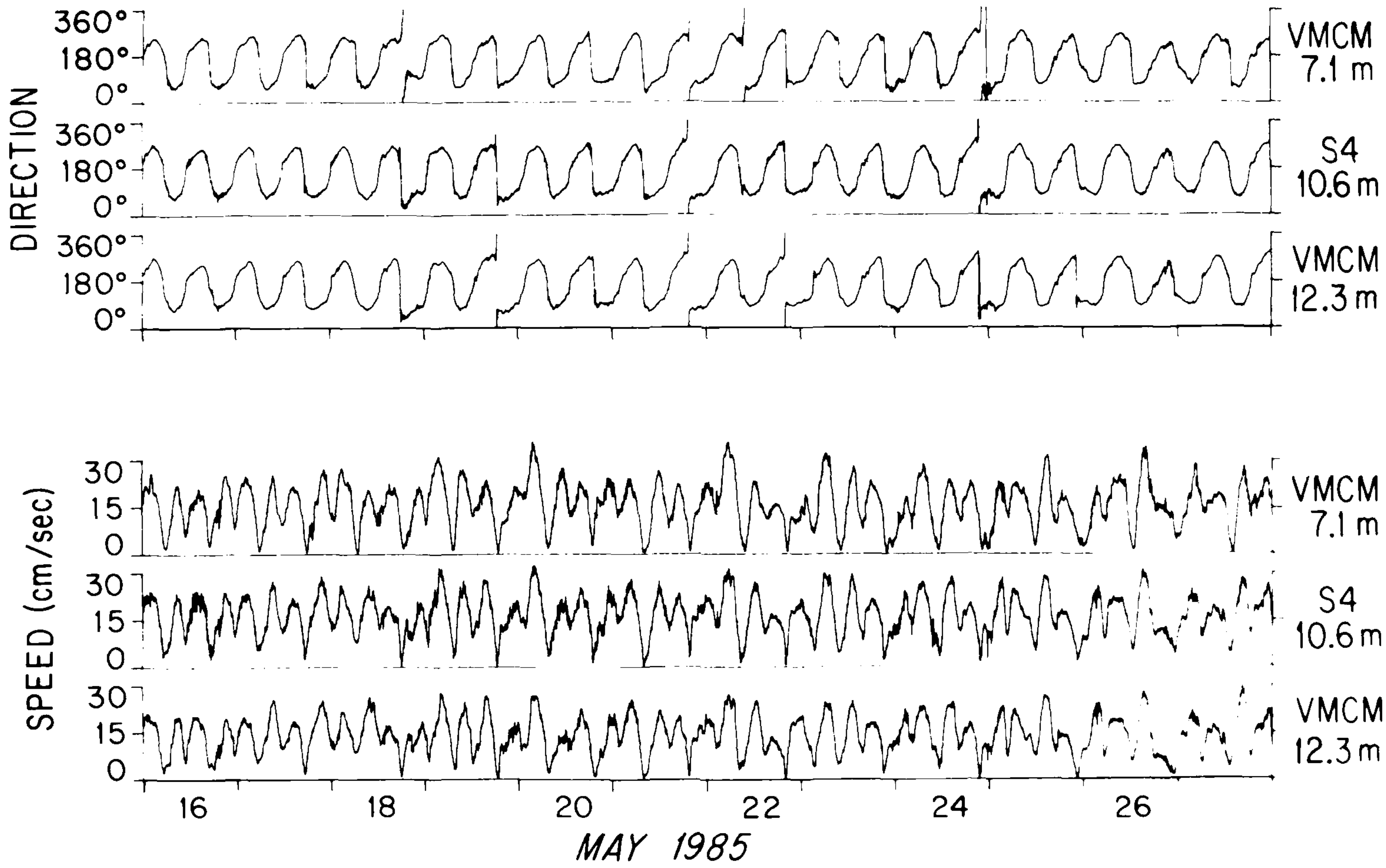


Figure 9. Buzzards Bay Mooring Schematic

clock. The real-time clock and sampling clock now have the same accuracy of 12 minutes/year.

A portion of the (2) VMCM and S4 speed and direction time series plots is shown in Figure 10. The VMCM at 12.3m and the S4's time series of the first 16 days of data were compared. Results show that while the speed difference between the two instruments decreases with increasing flow speed, the S4 recorded a higher speed on average over the entire flow range observed (2 cm/sec. in the 10 to 20 cm/sec range). The direction difference between the S4 and VMCM does not decrease with increasing flow speed, but has an overall standard deviation of 8.5°. Although the cause of these discrepancies is not entirely clear at present, a simple model of the known under-response of the VMCM suggests that the absolute accuracy of the S4 may be quite good. Further information on this experiment can be found in a paper entitled "A VMCM S4 Current Meter Intercomparison on a Surface Mooring in Shallow Water" (Beardsley, et al., 1985).



10. Buzzards Bay Mooring VMCM/S4 Time Series

4. Conclusions and Recommendations

Much has been learned about the relatively new InterOcean S4 current meter. As common with new instrumentation, these current meters had initial problems. For example, electronic component failures have caused excessive current drains resulting in early battery depletion with a loss of data retrieved. A drifting clock caused a time base difficulty in processing the data when the S4 was run in the "continuous mode."

In the Woods Hole Oceanographic Institution's Buoy Group, experience has shown that problems normally occur, and in fact, are expected during the early life of a new instrument. It has become a standard practice to test or "burn in" a new instrument for a period of six months or more in either a cold ($0^{\circ}C$) or room temperature environment. This practice has been beneficial in forcing lurking problems to occur, enabling corrections to be made before actual instrument deployment at sea. Experience with the S4 current meter has supported this burning in period.

The three standard memory InterOcean S4 current meters tested now seem to be performing up to their specifications. The current drain is one of the most obvious indications of a problem and should be checked periodically. The optional sensors could perform significantly more accurately with software compensation provided on an individual basis.

In many long term deep sea applications these instruments would be short of memory and depth capability. InterOcean has recently addressed both these areas and now offers memory expansion options, including a

256K memory which would increase the capacity of our units by 400%. The depth limitation has been overcome by the development of a new S4 which goes to 6000m by using a 10" glass sphere for a pressure housing and a titanium mooring rod for a strength member.

The S4 current meters are small and light and therefore easy to handle both at sea and in the lab. Providing little drag and weight, the S4 requires less flotation to hold it up in mooring applications. Additionally, with no external moving parts, the instrument is much less susceptible to mechanical failures. The S4 seems to work well in both high speed subsurface and dynamic surface moorings where many other current meters fall short. These positive qualities make the S4 a versatile and promising current measuring instrument.

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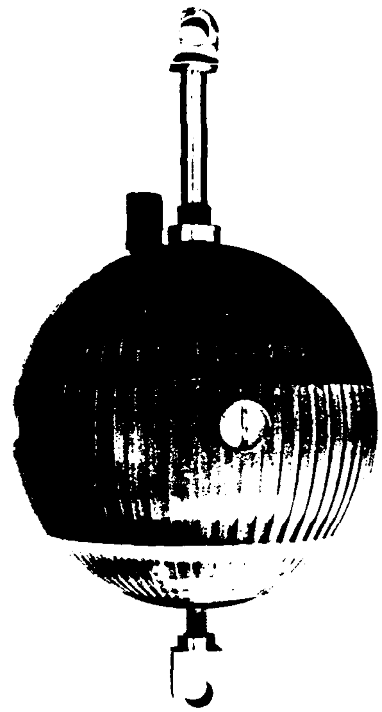
APPENDIX A - Maufacturer's Data and Specification Sheet

S4 CURRENT METER



SPHERICAL SOLID STATE SENSOR

ADVANCEMENT IN DESIGN

The S4 current meter is a spherically solid, microprocessor driven instrument which records data in any manner desired with high accuracy and reliability in a sealed easy to use housing.

HYDRODYNAMICALLY DESIGNED

The S4 has no delicate, moving parts or fragile sensors. This minimizes the chance of handling damage or fouling. The unique grooved surface of the S4 produces stable hydrodynamic characteristics and ensures exceptional linearity and stability.

SOFTWARE CONTROLLED

The EPROM formatted microprocessor affords unprecedented flexibility and simplicity of use. The S4's low power CMOS microprocessor performs vector overaging, burst, and adaptive sampling. The instrument can alter its recording format in response to oceanographic events. Customized programs can be developed to meet the researcher's special needs.

IS SOLIDLY BUILT

The sphere is made of high strength dimensionally stable plastic with a titanium main load bearing shaft. The compass and all electronics including data storage and power supply are sealed within the sphere.

SOLID STATE MEMORY

Information is stored in a solid state memory for more reliable data storage and is retrieved through an RS232 port to the user's terminal, computer or other storage device.

S4 APPLICATIONS

The S4 may be used in any body of water, fresh or salt, and deployed up to 1000 meters deep. It is particularly valuable (1) near the surface where the S4's excellent horizontal and vertical cosine response is needed, (2) in low current regimes where exceptional stability and resolution are needed, (3) in very high flow regimes where the S4's low drag and lack of moving parts permit practical deployment without concern for fragility. Options include conductivity, temperature and depth.

ELECTROMAGNETIC SENSOR

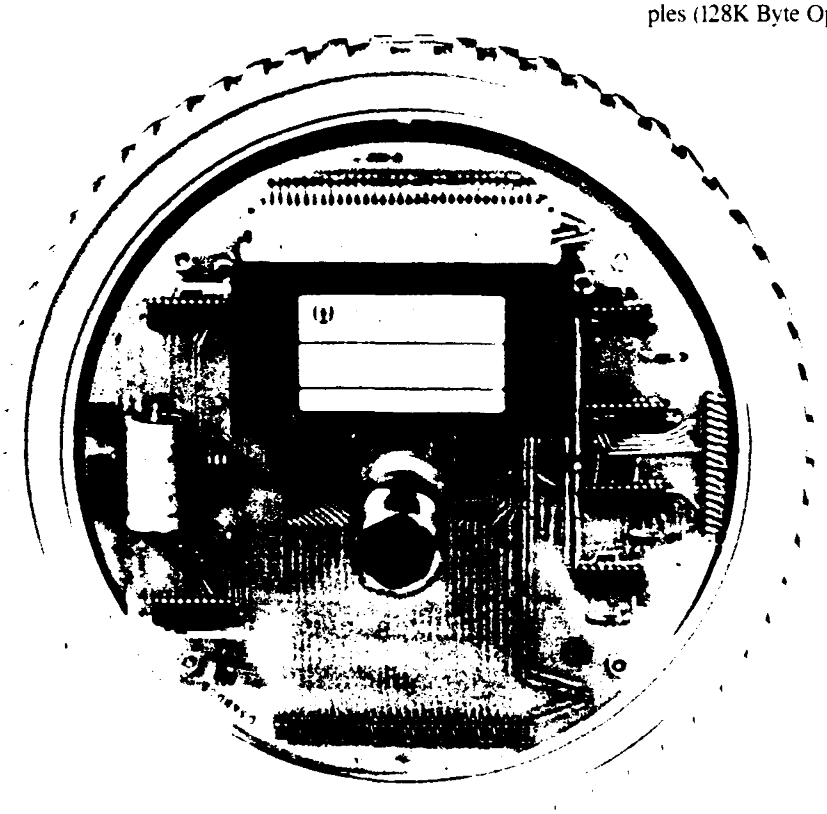
The S4 has been designed to measure the true magnitude and direction of current motion in any ocean environment, including areas of vertical water movement and low current regimes. Water flows through the electromagnetic field created by the instrument, thereby producing a voltage which is proportional to the magnitude of the water velocity. This voltage is then sensed by the two pairs of titanium electrodes located symmetrically on each side of the spherical housing. The S4 is unique in that the instrument housing is the sensor. There is no mechanical motion, protruding parts or sensor support structures to interfere with the flow pattern. There is nothing to break or foul. This new hydrodynamic design in which the instrument body itself is the source of current measurement represents a technological breakthrough. The S4 has withstood rigorous performance testing and achieved excellent and stable directional response. The internal fluxgate compass operates within specification when the S4 experiences a full 25 degree tilt range.

S4 MEMORY MODULE

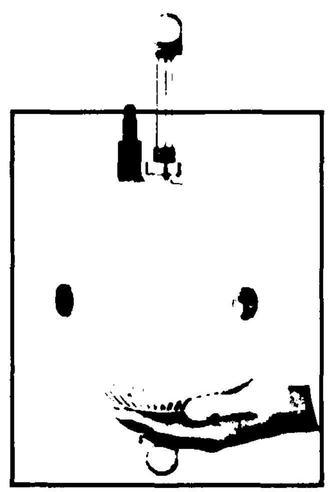
Powerful Memory Inside
So You Don't Have To
Open The Case.

RECORDER

CMOS static RAM 64 Byte (Optionally 128K Byte) 40,000 N, E Vector averaged pairs > 1 year using 15 minute samples (128K Byte Option).



Small and
Lightweight.



INSTRUMENTATION AND ACCESSORIES

S4 responses are shown (—•—) ideal responses (—)

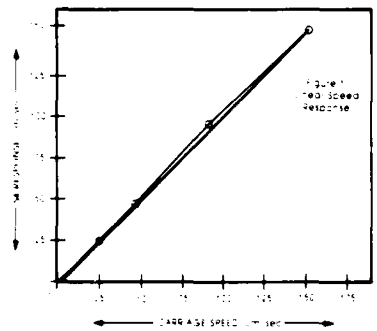


Figure 1 shows the S4's linear speed response. Earlier electromagnetic sensors have smooth surfaces. Their hydrodynamic characteristics change at certain turbulence, vibration, and temperature dependent speeds, resulting in non-linear and unstable response. The S4's unique *grooved surface* products stable hydrodynamic characteristics and ensures exceptional *linearity* and *stability*.

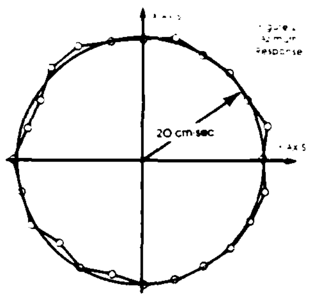


Figure 2 displays the S4's azimuth (horizontal) response in polar form. The speed error is less than 0.7 cm/sec (0.02 ft/sec), resulting in unusually accurate current measurement, unaffected by current direction.

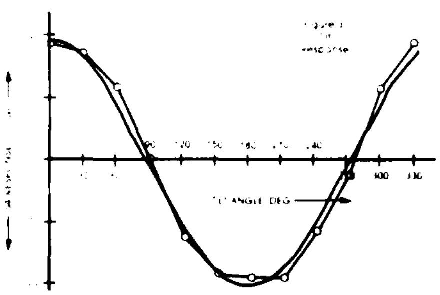


Figure 3 shows that the S4's tilt response closely approximates a cosine function, necessary for accurate performance in the presence of wave or mooring induced vertical motion. Important note: the response shown is that of the *complete current meter*, not simply that of a current sensor. Other *sensors* demonstrate comparable responses, but their accuracy degrades when mounted to bulky and asymmetric housings.

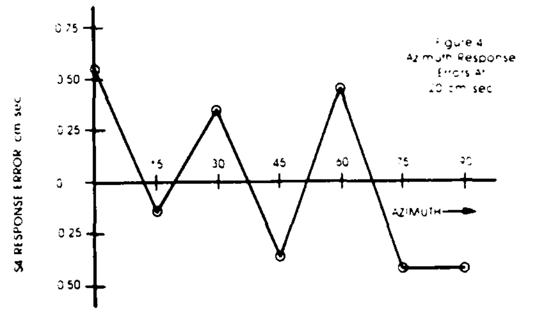


Figure 4 demonstrates the S4's azimuth response in greater detail. Note the extreme scale expansion: error is less than only 0.55 cm/sec (.018 ft/sec).

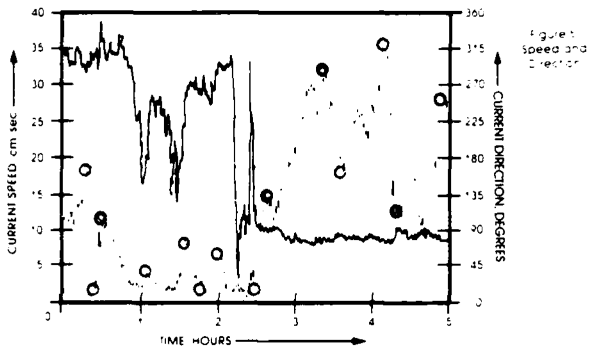
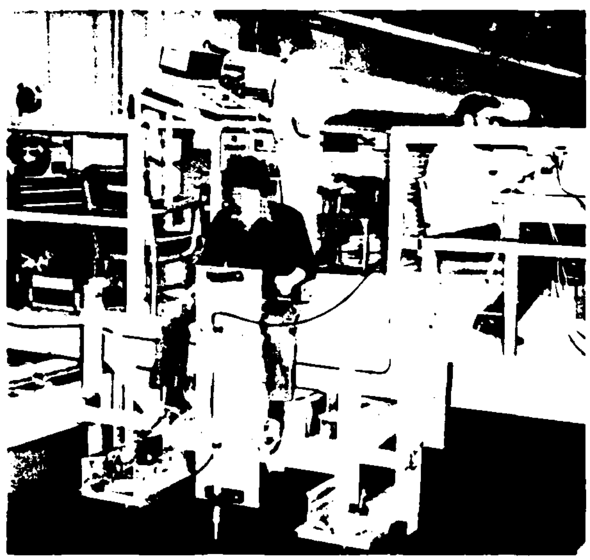


Figure 5 depicts current speed and direction recorded during the first ocean deployment of the S4. The first half of the graph shows the diminishing westward tidal current. The remainder shows the increasing easterly current. Note the ability of the S4 to resolve small currents well below the stall speeds of rotor instruments.



Performance Testing being conducted at National Space Technology Laboratory.

ENGINEERING DATA & SPECIFICATIONS

SPEED SENSOR

TYPE:	Electro-Magnetic, 2 Axis
RANGE:	0-350 cm/sec (0-11.5 ft/sec)
RESOLUTION:	0.2 cm/sec (0.007 ft/sec)
ACCURACY:	2% Reading +/- 1 cm/sec (0.03 ft/sec)

COMPASS

TYPE:	Flux-Gate Magnetometer
TILT:	+/- 25°
RESOLUTION:	0.5°
ACCURACY:	2°

TIME KEEPING

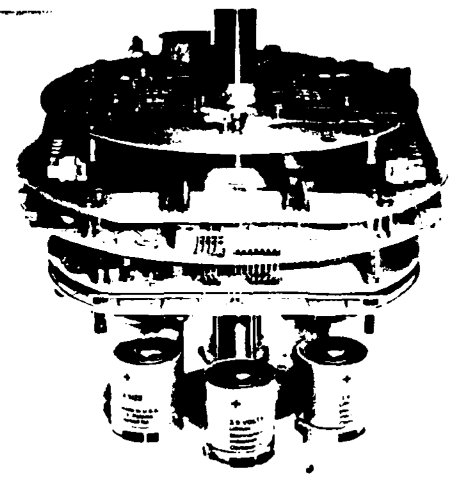
TYPE:	Quartz Oscillator
POWER:	Non-restricted lithium battery
LIFE:	5 years, factory set to GMT (may be reset using a terminal)
ACCURACY:	12 min/year

CONTROL

TYPE:	EPROM Controlled Micro-processor
FORMAT:	Vector average, burst, adaptive, combination; externally programmable and/or default.

POWER SUPPLY

TYPE:	Internal batteries (6 alkaline "D" cells) (Lithium Optional)
ENDURANCE:	2800 hours continuous operation, 5 years total deployment, with on time equal to 2800 hours (Lithium option)



PRESSURE (Optional)

TYPE:	Semi-Conductor Strain Gauge
RANGE:	0-1000 dBar (others optional)
RESOLUTION:	1 dBar
ACCURACY:	5 dBars (Optional, 1 dBar)

TEMPERATURE (Optional)

TYPE:	Thermistor
RANGE:	-2.5 to 36°C
RESOLUTION:	0.05°C
ACCURACY:	+/- 0.1°C
RESPONSE TIME (63%):	1 Minute

CONDUCTIVITY (Optional)

TYPE:	Inductive
RANGE:	1-70 mS/cm
RESOLUTION:	0.1 mS/cm
ACCURACY:	+/- 0.20 mS/cm

MECHANICAL/ENVIRONMENTAL

SIZE:	Sphere, diameter 25 cm (10 inch)
WEIGHT:	Air, 8 kg (24 pounds) Water, 4 pounds
MOORING:	In-line (Optional off-line brackets)
THROUGH LOAD:	4500 kg (10,000 pounds), working
PAD EYES:	Insulating liner, accepts 1.6 cm (5/8 inch) shackle pin
MATERIAL:	Sphere, glass-filled cycloaliphalic epoxy, mooring rod, titanium 6 AL-4V
DRAG:	8 kg (18 pounds) at 250 cm/sec (8 ft/sec)
DEPTH:	1000 meters (3200 ft)
TEMPERATURE:	Storage, -40 to +70°C Operating, -2.5 to +36°C

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16. Abstract (Limit: 200 words)
This report reviews the working principles of the InterOcean S4 electromagnetic current meter and outlines the practical difficulties and engineering solutions to convert these basic principles into a working instrument.

Presented are the test procedures and results performed on three production units placing emphasis on the oceanographic user's point of view. These tests, performed by the Ocean Structures and Moorings Laboratory, Ocean Engineering Department, Woods Hole Oceanographic Institution (WHOI), include laboratory, dockside, and both surface and subsurface mooring tests. S4s are compared to each other to other types of current meters in various intercomparison tests.

Results of this evaluation program are next summarized. Also, suggestions for areas of improvement and further developments are made. Finally, recommendations for the acceptance, calibration, and burning in of new instruments conclude the report.

17. Document Analysis a. Descriptors

1. current meter
2. electromagnetic current meter
3. InterOcean

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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